Pacific Science (1983), vol. 37, no. 1

The Vegetation and Environment of the Crater District of Haleakala National Park[1]

LOUIS D. WHITEAKER[2]

ABSTRACT: A vegetation map of the Crater District of Haleakala National Park was produced at a scale of 1 : 24,000, which can be used as an overlay of the U.S. Geological Survey 1 : 24,000 topographic quadrangle maps. Fifty-three structural-floristic communities, which were grouped into four structural vegetation types, were mapped. Areas were calculated for each community using an electronic planimeter. Topographic vegetation profiles were constructed that show changes in vegetation types in relation to climatic gradients. Correlations were observed between certain substrates and community types. Phytosociological analysis of relevé data by the synthesis table technique and the dendrograph technique resulted in ecologically meaningful groupings of the sample stands.

A SURVEY OF THE LITERATURE (Whiteaker 1978) has shown that in different tropical alpine and subalpine ecosystems, similar plant communities have been described at equivalent elevations. These similarities are the result of environmental factors that have had an evolutionary impact on plant life forms in spite of biogeographic isolation. Characteristic community types of those tropical, high mountain areas are ericaceous scrub, tussock grassland, arborescent and rosette life forms, and high-altitude desert. In this study I tested the hypothesis that the same community types described for other tropical alpine and subalpine ecosystems also occur in the Crater District of Haleakala National Park.

The objectives of this study were twofold. The first objective was to produce a large-scale vegetation map that indicates the actual vegetation of the Crater District of Haleakala National Park using structural-floristic map unit symbols similar to those used for Hawaii Volcanoes National Park (Mueller-Dombois and Fosberg 1974). These vegetation units were to be verified and quantified. The second objective was to associate the mapped vegetation patterns with environmental factors. Larson (1969) edited a report that recommended the production of detailed vegetation, soil, topographic, and climatic overlay maps as needed research. This study is one step toward the fulfillment of that need.

STUDY AREA

Geography

Haleakala National Park is located in the southeastern part of the island of Maui in the Hawaiian Archipelago at latitude 20°45′ N and longitude 156°12′ W (Figure 1). This eastern part of the island is formed by the large shield volcano of Haleakala. The study area is the Crater District which incorporates Haleakala Crater (12.1 km long, 4.0 km wide), small adjacent segments of the outer slopes, and portions of two broad erosional depressions called gaps (Figure 2). Koolau Gap faces northeast and opens into Keanae Valley which runs to the ocean. Kaupo Gap faces south and opens into the pastureland of Kaupo Ranch. Elevations in the study area range from 1172.6 m (3847 ft) to 3055.0 m (10,023 ft) above sea level. Kipahulu Valley, lying east of the study area and facing southeast, was excluded from this study.

---

[1] Manuscript accepted 1 November 1982.
[2] Hawaii Field Research Center, Hawaii Volcanoes National Park, Hawaii 96718.

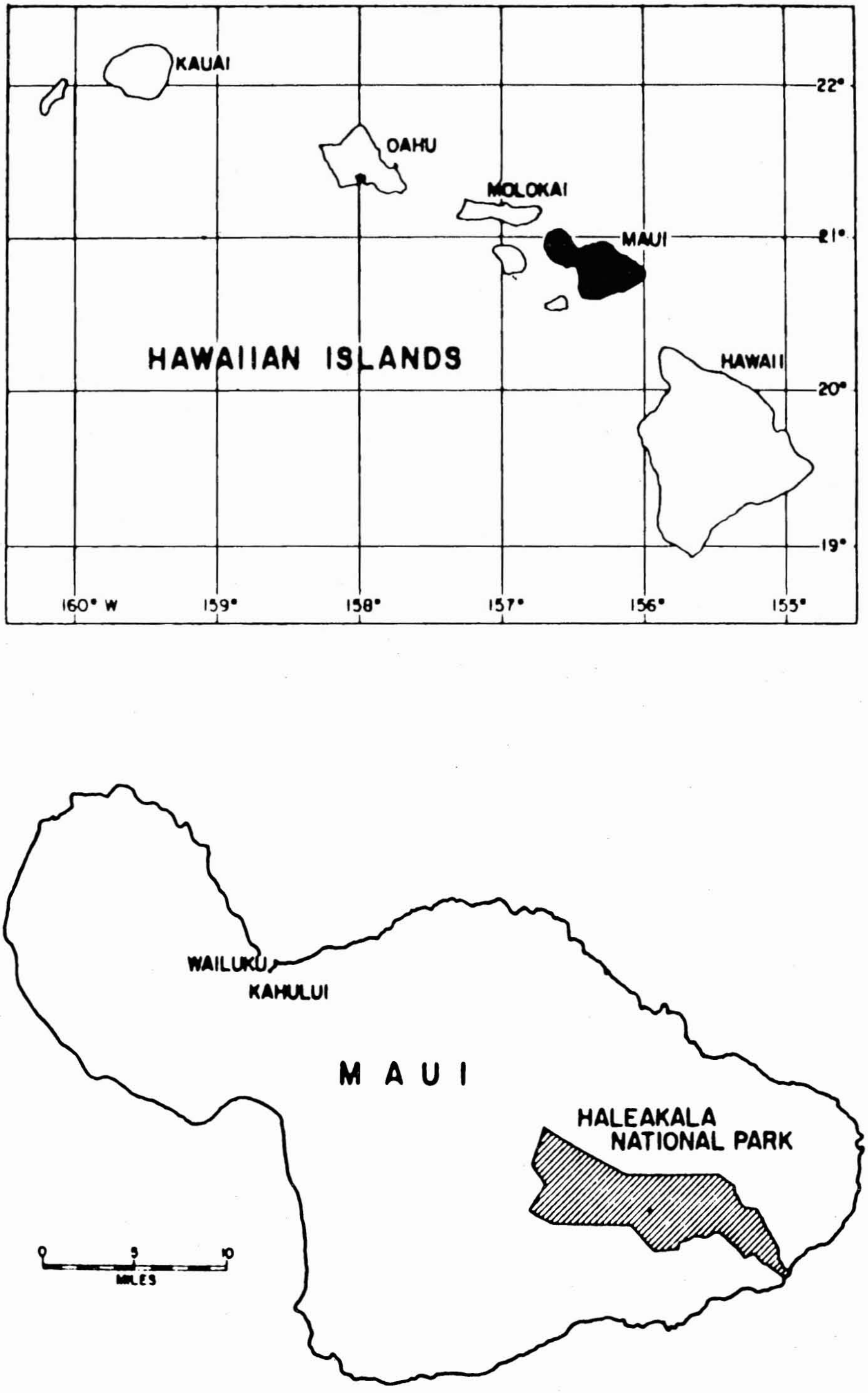


FIGURE 1. Map showing location of Haleakala National Park in reference to the Island of Maui and the Hawaiian Islands.

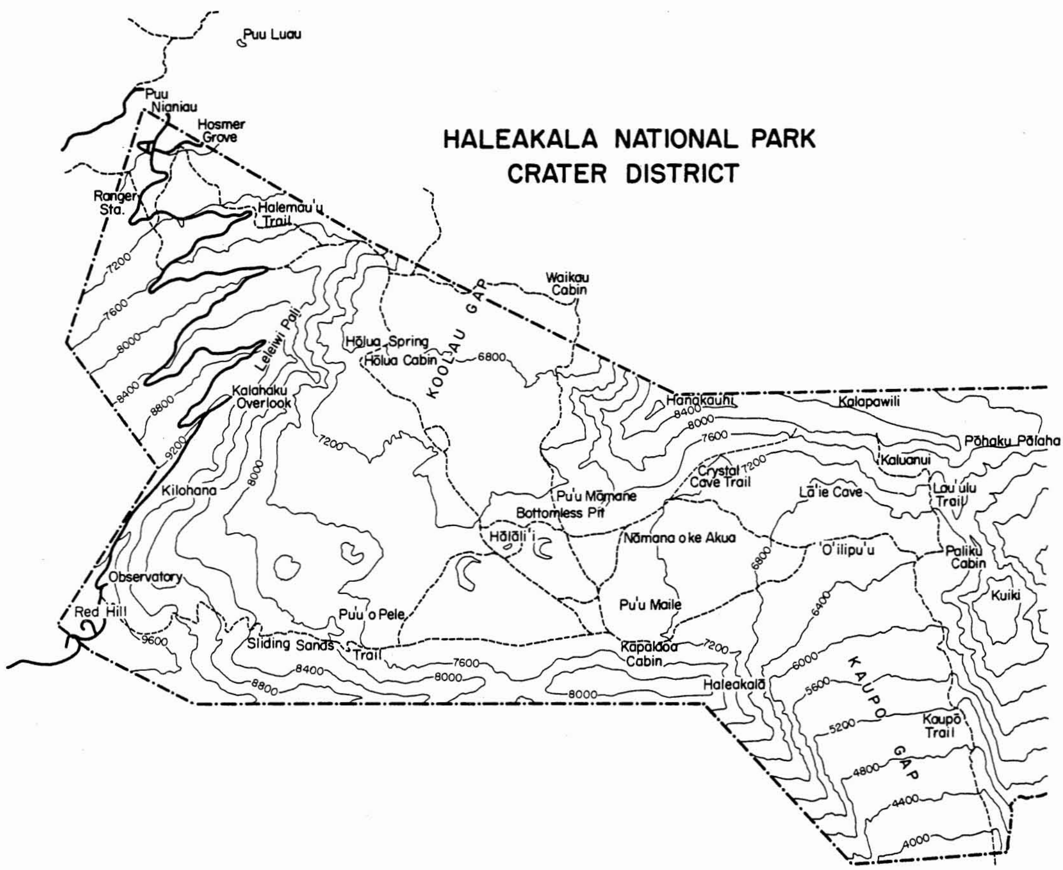


FIGURE 2. The Crater District of Haleakala National Park.

Geology and Soils

The geological history of Haleakala has been described by Macdonald and Abbott (1970). The mountain was formed by three series of volcanic activity. The first two, the Honomanu volcanic series and the Kula volcanic series, built up a large symmetrical shield volcano, much like Mauna Kea and Mauna Loa on Hawaii. The summit of this volcano may have been up to 915 m (3000 ft) higher than the present crater rim. After the Kula eruption series came a period of infrequent volcanic activity. Water cut deeply into the sides of the mountain, forming valleys all around. Keanae and Kaupo streams eventually cut into the very center of the mountain and formed a single huge erosional depression that extended entirely across the mountain top, divided only by a narrow ridge. In geologically recent times, the Hana volcanic series began. These lava flows covered the east and west slopes of the volcano and the floor of the depression. Great lava flows pushed through the Koolau and Kaupo gaps to the sea. The most recent eruption, estimated to have occurred about 1790, was on the southwest rift and is represented by two bare, black flows above La Perouse Bay.

As would be expected from the relative recency of volcanic activity on Haleakala, soils are young and relatively undeveloped. Almost all the soils of Haleakala have been classified as lithosols (rock) or regosols (cinder and ash) (Larson 1969). Some latosolic soils (brown forest soils) occurring near the park's northwest boundary are the only intrazonal soil classification in this section of the park (Cline 1955). The U.S. Soil Conservation Service's Soil Survey (1972) is based primarily on reconnaissance survey mapping units for the park and indicates an ash, cinder, rock or rock outcrop substrate, or rough mountainous terrain for almost all of the crater area.

Climate

The climate in Haleakala is varied with dry, moderately warm summers and cool, wet, windy winters. At Haleakala Ranger Station, elevation 2143 m (7042 ft), the mean monthly temperature ranges from 9.6°C (49°F) in February to 13.4°C (56°F) in August, a difference of only 3.8°C (7°F). Cloudy conditions are typical during midday all year. Snow has been recorded in the summit area, but it occurs only rarely and in the winter (Larson 1969).

The climate of the area, described by Blumenstock and Price (1967), is greatly influenced by a temperature inversion layer that accompanies the trade winds, which are present 50 to 70 percent of the time. The height of the inversion layer varies from day to day, but it is usually between 1525 and 2130 m (5000–7000 ft) elevation. The inversion layer suppresses the vertical movement of the air, restricting cloud formation to the zone beneath the inversion. This also results in a relative humidity generally below 40 percent above the cloud layer, with 10 or even 5 percent common.

The upper slopes of the high mountains receive some of the lowest amounts of precipitation in the state (Blumenstock and Price 1967). Average annual precipitation, however, does vary greatly within the park. Koolau Gap, at 2100 m (6890 ft) elevation, averages 2000 mm (78.7 in) precipitation while the summit averages only 800 mm (31.5 in) at 3000 m (9842 ft) elevation (Kobayashi 1973).

Flora

Since the cooler temperatures of higher latitudes occur only at higher elevations in Hawaii, the flora of Haleakala includes many plants representative of temperate zone groups. These north temperate zone taxa include *Fragaria*, *Artemisia*, *Silene*, *Vaccinium*, and the Madiinae, the subtribe of Compositae including *Argyroxiphium* and *Railliardia* (Carlquist 1970, Carr 1978). Genera with south temperate zone affinities include *Coprosma*, *Santalum*, *Wikstroemia*, and probably *Sophora*. Many of the high-altitude genera in Hawaii occur also at lower elevations including *Styphelia*, *Dodonaea*, *Santalum*, and *Sadleria* (Carlquist 1970).

The park flora also includes exotic species that have been introduced by humans and domestic animals (Larson 1969). These introductions have resulted in native species losing ground to invading forms, and there has been up to 100 percent alteration in species composition in some areas. Some of the more obvious and widespread of these genera include *Eupatorium*, *Hypochoeris*, *Oenothera*, *Pennisetum*, *Pinus*, *Rumex*, and *Eucalyptus*. Detailed plant lists for the Crater District have been compiled by the Cooperative National Park Resources Studies Unit of the University of Hawaii (CPSU/UH) (Berger et al. 1976, Stemmermann, Smith, and Hoe 1979).

Fauna

The park is rich in insects, most of which are endemic species that are restricted in their distribution. Many are associated with specific endemic plant species. Of the introduced insects in the area, the large blowflies, which breed in the carcasses of goats, are the most conspicuous since they are a considerable nuisance (Ruhle 1959). The CPSU/UH Resources Basic Inventory (RBI) also includes a survey of the insect species of the crater area (Berger et al. 1976; Stemmermann, Smith, and Hoe 1979).

The bird life of the crater includes several species of native birds including species in the endemic family Drepanididae. Most native species are difficult to spot and some are considered endangered. Introduced bird species are more commonly seen than native birds because the exotics are quite numerous and can be easily spotted along the roads and trails in the park (Ruhle 1959, Larson 1969).

No mammals are native to the Hawaiian

Islands except for the Hawaiian bat (*Lasiurus cinereus semotus*) (Larson 1969) and the Hawaiian monk seal (*Monachus schauinslandi*). When the Polynesians arrived in Hawaii, they brought pigs, dogs, and rats. After Captain Cook's arrival, many mammals were brought in, including goats, pigs, cattle, horses, sheep, cats, dogs, mice, and rats. Mongooses were imported with the intention of controlling the rat population. Established feral populations extend into the park, with only horses, sheep, and cattle no longer occurring as feral populations (Ruhle 1959, Larson 1969).

Ecology

There have been few ecological studies in the crater region, and of those that have been undertaken none has addressed the ecology of Haleakala Crater as a whole. Vegetation studies have mainly used structural criteria for classification. These include a simple vegetation map of the crater at a scale of approximately 1 : 62,500 (Larson 1969) and a description of the vegetation of the northeast outer slope (Vogl 1971). The phytosociology of the *Deschampsia* grassland on the northeast outer slope was described by Forehand (1970). Other ecological studies have been concerned with specific organisms found within the crater. The ecology of the silversword (*Argyroxiphium sandwicense* D.C.) has been studied by Kobayashi (1973). Yocum (1967) reported on the distribution and the ecological relationships of the park's goat population. The introduction of feral grazing animals, especially goats and pigs, has had severe effects on the ecology of the area. In the most heavily damaged areas several acres of exposed rocks are dotted here and there with mesa-like clumps of soil showing that at one time these areas were covered with six or more feet of topsoil held in place by native shrubs and grasses (Yocum 1967).

METHODS

Map Preparation

Black-and-white aerial photographs were obtained with a scale of 1 : 12,000. Vegetation boundaries were drawn on transparent overlays on these photographs using the structural units developed during an initial, thorough reconnaissance of the area. The accuracy of these units was field-checked. The classification and boundaries of the units were modified as field observations deemed necessary.

To produce a preliminary vegetation map, boundaries were hand-drawn on the USGS quadrangle maps. With the aid of field notes, the structural vegetation units were translated into symbols corresponding as closely as possible to the structural-floristic symbols used in the vegetation map of Hawaii Volcanoes National Park (Mueller-Dombois and Fosberg 1974).

Because there were problems with correction of the relief displacement, new photographs, 1 : 12,000 blowups of NASA false infrared color air photos, were obtained. Distortions were minimal in these photographs because of the high altitude from which they were taken and the stability of the aircraft at that altitude. The vegetation boundaries were transferred onto overlays on these photographs, with adjustments based on field notes. These photographs allowed further interpretation since different vegetation types showed variations in color.

The new overlays were photographically reduced to a scale of 1 : 24,000 resulting in transparent positives at the same scale as the USGS quadrangle maps. A small amount of relief displacement still remained in these positives. This was corrected by hand adjustment of the transparent positives to known topographic features on the quadrangle maps. These adjustments were made as needed to give the best possible representation of the true position of the vegetation boundaries. The adjustments, therefore, were not necessarily uniform in direction or amount throughout the entire map or even within a single transparent positive. The vegetation boundaries were traced on yet another overlay. This pencil tracing was again traced in ink. The vegetation units were labeled using a Varityper photographic typesetting machine and were then photographed again. Thus, a final vegetation map was produced that is approximately planimetrically correct at a scale of 1 : 24,000 and can overlay a composite of the USGS quadrangle maps that cover the Crater District of Haleakala National Park.

Quantitative Data Collection

The sampling of the plant communities was planned according to the relevé method as described by Mueller-Dombois and Ellenberg (1974). A total of 40 relevés were chosen with 15 in scrub communities, 15 in grassland communities, 5 in forest communities, and 5 in high-altitude desert communities. The relevés were placed in as even a geographic distribution as possible throughout the area to be mapped.

Because the flora is relatively poor in numbers of species, certain empirical values for the size of the relevés based on the structure of the vegetation were used: $100\,m^2$ ($10 \times 10\,m$) relevés for grassland communities, $200\,m^2$ ($10 \times 20\,m$) for scrub communities, $400\,m^2$ ($20 \times 20\,m$) for forest communities, and $400\,m^2$ ($20 \times 20\,m$) for high-altitude desert communities. Two additional relevés were established to make the sampling more complete. The total number of relevés was 42 (Figure 3).

Relevé Data Analyses

In a study of species distribution it is desirable to have an analytical methodology to demonstrate objectively the distribution patterns that is easily applicable to the relevé data collected in the field. The dendrograph technique and the synthesis table technique described by Mueller-Dombois and Bridges (1975) met the criteria and were used. A dendrograph is a two-dimensional diagram that displays the mutual relationships among a group of objects whose pairwise similarities are given. The dendrograph program of McCammon (McCammon and Wenniger 1970) was used because of its flexibility and tested usefulness.

For the synthesis table technique the same relevé data were used as for the dendrograph technique. The data were analyzed using the Ceska and Roemer (1971) program, which is a close simulation of the manual Braun-Blanquet synthesis table technique (Mueller-Dombois and Ellenberg 1974). The objective of the program is the extraction of those species groups from the table that optimally differentiate corresponding groups of relevés.

VEGETATION MAP AND PROFILE DIAGRAMS

Vegetation Map

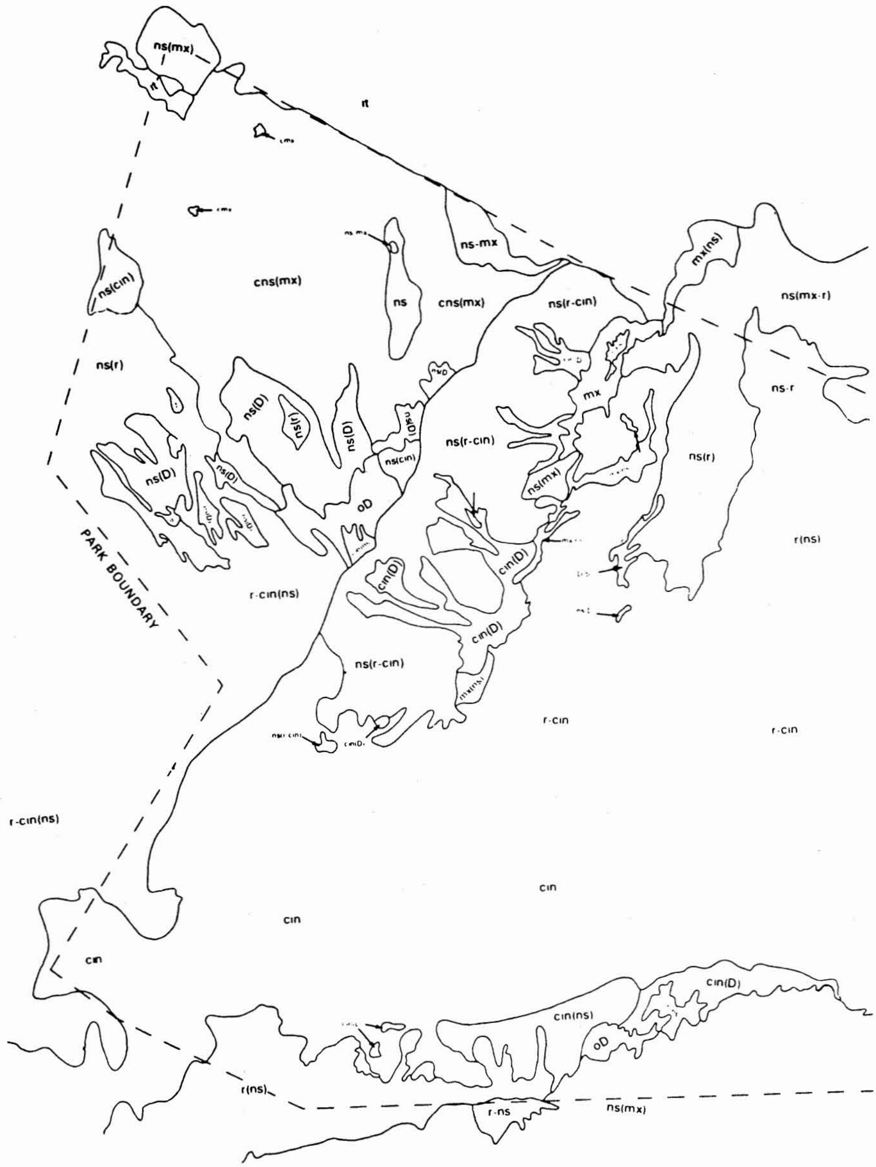
The final form of the vegetation map consists of labeled vegetation units outlined on a clear plastic overlay to a composite of the USGS quadrangle maps that cover the Crater District of Haleakala National Park.[3] The map is here presented on two facing pages with only vegetation boundaries and symbols shown (Figure 4).

The communities are labeled using a combination of symbols derived from generic names, plant cover designations, vegetation structure, substrate, or other predominant surface features. Symbol combinations usually contain a front symbol of letters, indicating the more obvious vegetation or surface features, and an attribute symbol added in parentheses after the front symbol to indicate a finer variation within those features (Mueller-Dombois and Fosberg 1974). Nineteen symbols were used to construct the map units on the vegetation map (Table 1).

The mapped vegetation was classified into 53 structural-floristic communities grouped into four structural vegetation types (Table 2). Forest communities were defined as those areas in which the tallest vegetation layer was composed of woody vegetation greater than or equal to 5 m (16 ft) in height with at least 30 percent crown cover. Scrub communities were defined as areas in which the uppermost vegetation layer was composed of woody species greater than 0.3 m (1 ft) but less than

[3] Copies of this final map are on file at Western Regional Headquarters of the National Park Service, Haleakala National Park Headquarters, and the University of Hawaii Department of Botany. A fold-out map on which both topographic contours and vegetation boundaries appear on a single sheet is included in the CPSU/UH technical report (Whiteaker 1980).

FIGURE 3. Locations of relevé sites.



KEY TO SYMBOLS

c	closed (>60% cover) used only in combinations	cin	cinder
o	open (30-60% cover) used only in combinations	Ac	Acacia koa
ns	native shrubs (Styphelia, Vaccinium, Coprosma, etc.)	D	Deschampsia australis
mx	mixed grasses (Holcus, Anthoxanthum, Poa, etc.)	Dd	Dodonaea eriocarpa (individuals of tree stature)
r	rock (commonly pahoehoe or a'a lava)	Eu	Eupatorium adenophorum
it	introduced trees (Eucalyptus, Pinus, etc.)	Hl	Holcus lanatus

(ns) symbol in parenthesis are scattered, sparse (<30% cover) or as an understory of or matrix between the vegetation of the preceding symbol used only in combinations

VEGETATION MAP OF THE CRATER DISTRICT, HALEAKALA NATIONAL PARK, MAUI, HAWAII

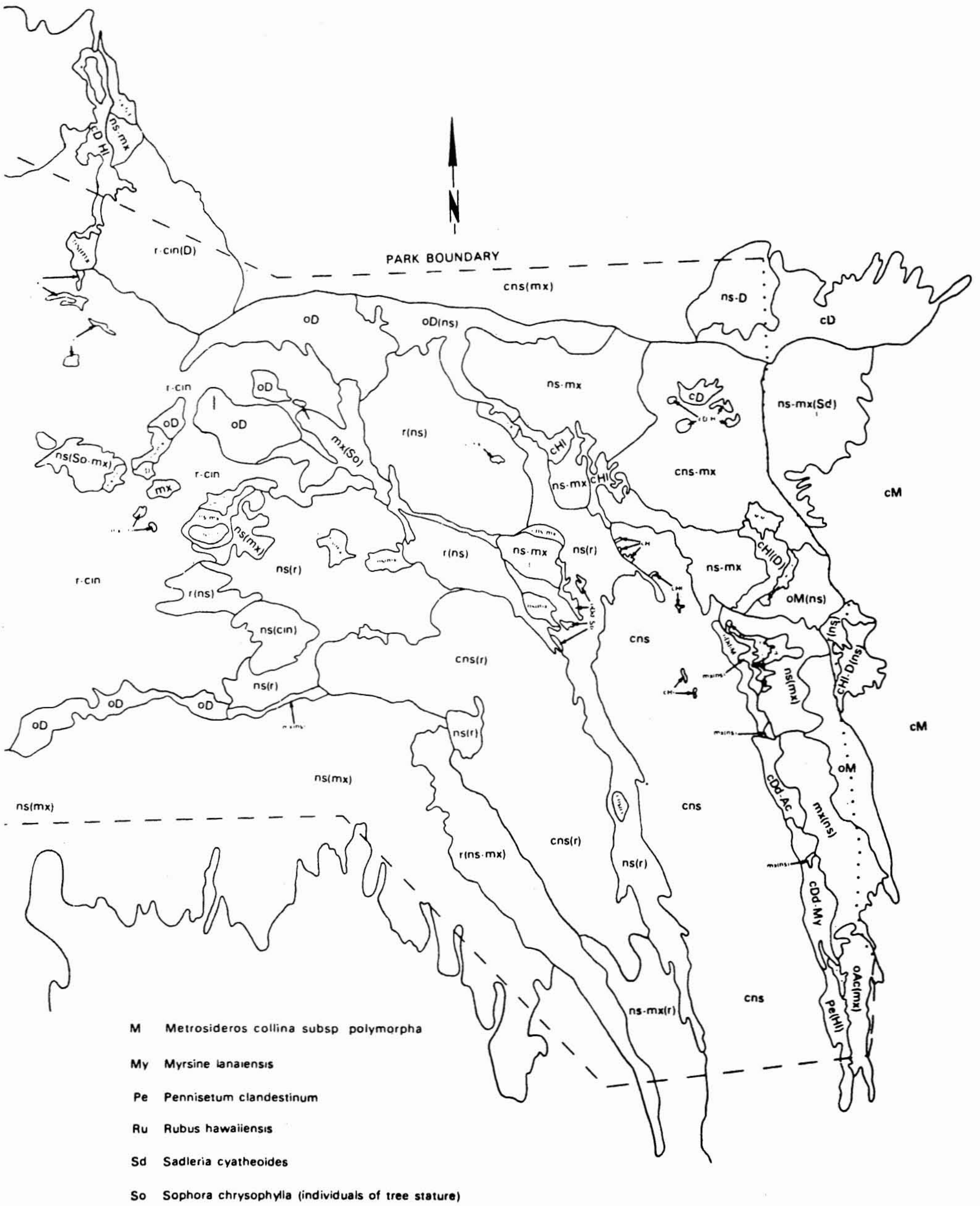


FIGURE 4. Vegetation map. (Approximate scale = 1:56,000.)

TABLE 1

EXPLANATION OF MAP SYMBOLS USED FOR VEGETATION UNIT DESCRIPTIONS

SYMBOL	EXPLANATION	SYMBOL	EXPLANATION
Ac	*Acacia koa*	ns	Native shrubs (*Styphelia*, *Vaccinium*, *Coprosma*, etc.)
c	Closed (>60% cover) used only in combinations	o	Open (30–60% cover) used only in combinations
cin	Cinder	Pe	*Pennisetum clandestinum*
D	*Deschampsia australis*	r	Rock (commonly pahoehoe or a'a lava)
Dd	*Dodonaea eriocarpa* (individuals of tree stature)	Ru	*Rubus hawaiiensis*
Eu	*Eupatorium adenophorum*	Sd	*Sadleria cyatheoides*
Hl	*Holcus lanatus*	So	*Sophora chrysophylla* (individuals of tree stature)
it	Introduced trees (*Eucalyptus*, *Pinus*, etc.)	(xy)	Symbol in parentheses indicates scattered or sparse cover (<30%) or as an understory of or matrix between the vegetation of the front symbol, used only in combinations
M	*Metrosideros collina*		
mx	Mixed grasses (*Holcus*, *Anthoxanthum*, *Poa*, etc.)		
My	*Myrsine lanaiensis*		

TABLE 2

SYMBOLS AND NAMES OF MAPPED VEGETATION UNITS

MAP SYMBOL	COMMUNITY NAME
Forest communities	
cM	Closed *Metrosideros* forest
cDd-My	Closed *Dodonaea* and *Myrsine* forest
cDd-Ac	Closed *Dodonaea* and *Acacia* forest
oM	Open *Metrosideros* forest
oM(ns)	Open *Metrosideros* forest with a native scrub understory
oM-My(Sd)	Open *Metrosideros* and *Myrsine* forest with much *Sadleria* in the understory
oDd(M)	Open *Dodonaea* forest with scattered *Metrosideros* individuals
oDd-So	Open *Dodonaea* and *Sophora* forest
oAc(mx)	Open *Acacia* forest with a mixed grass matrix
oM-So(ns)	Open *Metrosideros* and *Sophora* forest with an understory of native shrubs
it	Introduced trees (*Eucalyptus*, *Pinus*, etc.)
Scrub communities	
cns	Closed native scrub on substrates of various particle size
cns(mx)	Closed native scrub with a mixed grass matrix
cns-mx	Closed native scrub with a closed cover mixed grass matrix
cns(r)	Closed native scrub on a rock substrate
ns	Open native scrub on substrates of various particle size
ns(cin)	Open native scrub on a cinder substrate
ns(r)	Open native scrub on a rock substrate
ns(mx)	Open native scrub with a mixed grass matrix
ns-mx	Open native scrub with a mixed grass matrix having open to closed cover
ns-mx(Sd)	Open native scrub with an open to closed mixed grass matrix and scattered *Sadleria* ferns
ns-mx(r)	Open native scrub with an open mixed grass matrix on a rock substrate
ns(So-mx)	Open native scrub with scattered *Sophora* trees and a mixed grass matrix
ns(r-cin)	Open native scrub on a rock and cinder substrate
ns(mx-r)	Open native scrub with a matrix of mixed grasses and exposed rock
ns(D)	Open native scrub with a *Deschampsia* grass matrix
ns-D	Open native scrub with a *Deschampsia* grass matrix having open to closed cover
ns-r	Open native scrub with a matrix of exposed rock having nearly equal cover
cRu-mx	Closed *Rubus* patch with a closed mixed grass matrix
cEu(mx)	Closed *Eupatorium* patch with a mixed grass matrix

TABLE 2 (*continued*)

MAP SYMBOL	COMMUNITY NAME
Grassland communities	
cD	Closed *Deschampsia* grassland
cD-Hl	Closed *Deschampsia* and *Holcus* grassland
cHl-D(ns)	Closed *Holcus* and *Deschampsia* grassland with scattered native shrubs
cHl(D)	Closed *Holcus* grassland with scattered *Deschampsia* tussocks
cHl	Closed *Holcus* grassland
Pe(Hl)	Closed *Pennisetum* grassland with scattered *Holcus*
cmx	Closed mixed grass grassland
oD	Open *Deschampsia* grassland
oD(ns)	Open *Deschampsia* grassland with scattered native shrubs
oD(So)	Open *Deschampsia* grassland with scattered *Sophora* trees
mx	Mixed grasses
mx(ns)	Mixed grasses with scattered native shrubs
mx(So)	Mixed grasses with scattered *Sophora* trees
mx(Sd)	Mixed grasses with scattered *Sadleria* ferns
High-altitude desert communities	
cin	Barren cinder
cin(ns)	Barren cinder with scattered native shrubs
cin(D)	Barren cinder with scattered *Deschampsia* grass tussocks
r-cin	Barren rock and cinder
r-cin(ns)	Barren rock and cinder with scattered native shrubs
r-cin(D)	Barren rock and cinder with scattered *Deschampsia* grass tussocks
r(ns)	Barren rock with scattered native shrubs
r(ns-mx)	Barren rock with scattered native shrubs and mixed grasses
r-ns	Barren rock with native shrubs

5 m in height with a crown cover exceeding 30 percent. Grassland communities were defined as areas in which grass species had more than 30 percent cover but where the cover of woody species was less than 30 percent. High-altitude desert communities were defined as areas having less than 30 percent total plant cover. Cover was defined as the vertical projection of the crown or shoot area of a species to the ground and expressed as a percent of the reference area (Mueller-Dombois and Ellenberg 1974). Closed cover was defined as 60 percent or more cover. Open cover was defined as 30–60 percent cover. Sparse cover was defined as less than 30 percent cover. These cover designations were applied to a single layer of the vegetation. For example, a community may be termed an open cover forest community with a closed cover shrub layer composing the understory.

Areas for the vegetation communities mapped at 1 : 24,000 were determined using an electronic planimeter (Table 3). The total area mapped was determined to be 7544.8 hectares (18,643 acres). Scrub communities had the largest total area of 3691.7 hectares (9122 acres). Forest communities had the smallest total area of 164.9 hectares (407 acres). In terms of area the most common map unit encompassed those areas where the rock and cinder substrate was the dominant surface feature (r-cin). This single unit had a total area of 1119.5 hectares (2766 acres), larger than the total for forest communities and grassland communities combined. In terms of frequency the most common community was open cover mixed grasses with scattered native shrubs [mx(ns)]. This community was mapped 15 times but had a total area of only 111.2 hectares (275 acres). In terms of area the most common map unit with significant vegetation cover (greater than 30 percent) was closed native scrub with a mixed grass matrix [cns(mx)]. This community covered 611.6 hectares (1511 acres) of the study area.

TABLE 3

TOTAL AREA MAPPED BY VEGETATION TYPES AND MAP UNITS

STRUCTURE AND MAP UNIT	AREA	
	HECTARES	ACRES
Forest		
cDd-My	19.09	47.18
cDd-Ac	10.71	26.46
cM	2.06	5.09
oM	42.81	105.77
oM(ns)	23.76	58.72
oM-So(ns)	4.82	11.91
oM-My(Sd)	4.19	10.36
oDd(M)	8.39	20.73
oDd-So	4.19	10.35
oAc(mx)	21.35	52.76
it	23.53	58.14
Total	164.90	407.47
Scrub		
cns	407.76	1007.57
cns(mx)	611.55	1511.12
cns-mx	141.75	350.27
cns(r)	278.66	688.57
ns(cin)	59.34	146.62
ns(r)	537.34	1327.74
ns(mx)	588.65	1454.53
ns(So-mx)	14.12	34.89
ns(r-cin)	284.81	703.76
ns(mx-r)	167.49	413.87
ns(D)	131.28	324.40
ns-D	35.04	86.58
ns-mx	199.54	493.06
ns-mx(Sd)	80.74	199.50
ns-mx(r)	81.42	201.18
ns-r	48.50	119.83
ns	16.60	41.02
cEu(mx)	1.91	4.73
cRu-mx	5.18	12.79
Total	9122.03	3691.68
Grassland		
cD	80.58	199.12
cD-Hl	21.45	53.00
cmx	0.63	1.56
cHl	17.11	42.29
cHl(D)	11.89	29.39
cHl-D(ns)	14.58	36.02
Pe(Hl)	12.70	31.38
oD	168.11	415.40
oD(ns)	57.01	140.87
oD(So)	5.14	12.71
mx(So)	32.78	81.01
mx(Sd)	6.31	15.60
mx(ns)	111.23	274.85
mx	29.04	71.76
Total	568.56	1404.96
High-altitude desert		
cin	1015.59	2509.48
cin(ns)	61.72	152.51
cin(D)	110.91	274.06
r-cin	1119.46	2766.15
r-ns	2.34	5.78
r-cin(ns)	157.80	389.93
r-cin(D)	103.29	255.22
r(ns)	450.97	1114.34
r(ns-mx)	97.59	241.15
Total	3119.67	7708.62
Grand Total	7544.81	18643.08

Profile Diagram

Three topographic vegetation profiles were constructed to aid in the interpretation of the map units. The courses of these profiles are shown on a reference map of the park (Figure 5). These courses were chosen to cross as much of the study area as possible while illustrating as much of the range in vegetation types and environmental variables as possible. Profile 1 (Figure 6) runs from the park boundary at Puu Nianiau on the northwest outside slope at 2087.5 m (6849 ft) to Kilohana on the west rim of the crater at 2926.1 m (9600 ft). Profile 2 (Figure 7) runs from Kilohana, across the crater floor, to the east rim of the crater above Paliku Cabin (1945 m) that separates Haleakala Crater from Kipahulu Valley at 2133.6 m (7000 ft). Profile 3 (Figure 8) runs from the southern park boundary in Kaupo Gap at 1158.2 m (3800 ft), up over Kalapawili Ridge at 2484 m (8150 ft), to the northern park boundary on the north outside slope at 2316.5 m (7600 ft).

In profile 1 (Figure 6) decreases in both mean annual precipitation and mean annual temperature are associated with the increase in elevation. An apparent effect of the temperature gradient can be seen at about 2590.8 m (8500 ft) where the vegetation becomes very sparse and can be termed a high-altitude desert. This change may be associated with the diurnal frost boundary, above which freezing temperatures occur at ground level every night of the year, which was found to occur at approximately this elevation on Mauna Loa

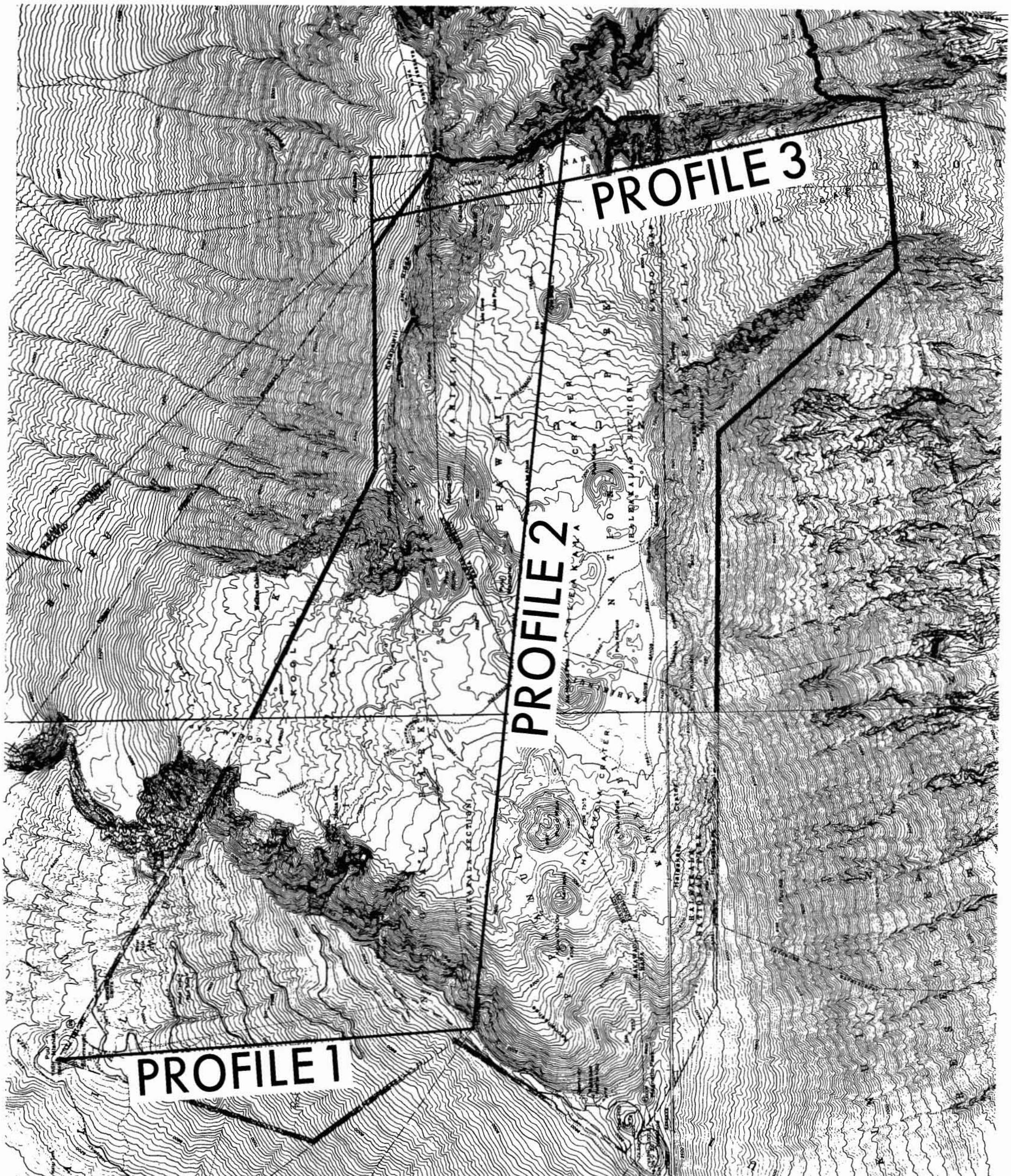


FIGURE 5. Courses of the topographic vegetation profiles.

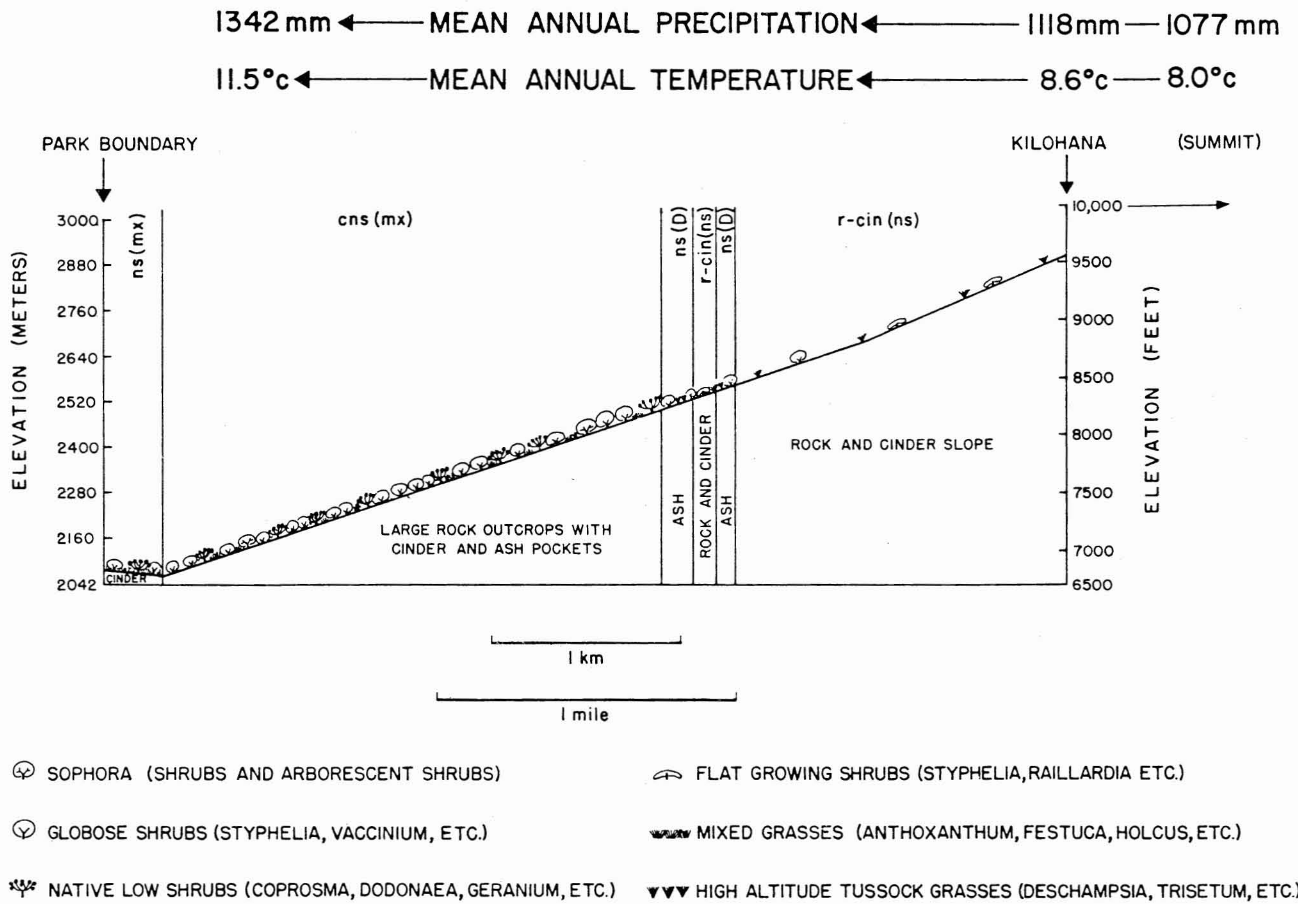


FIGURE 6. Topographic vegetation profile 1.

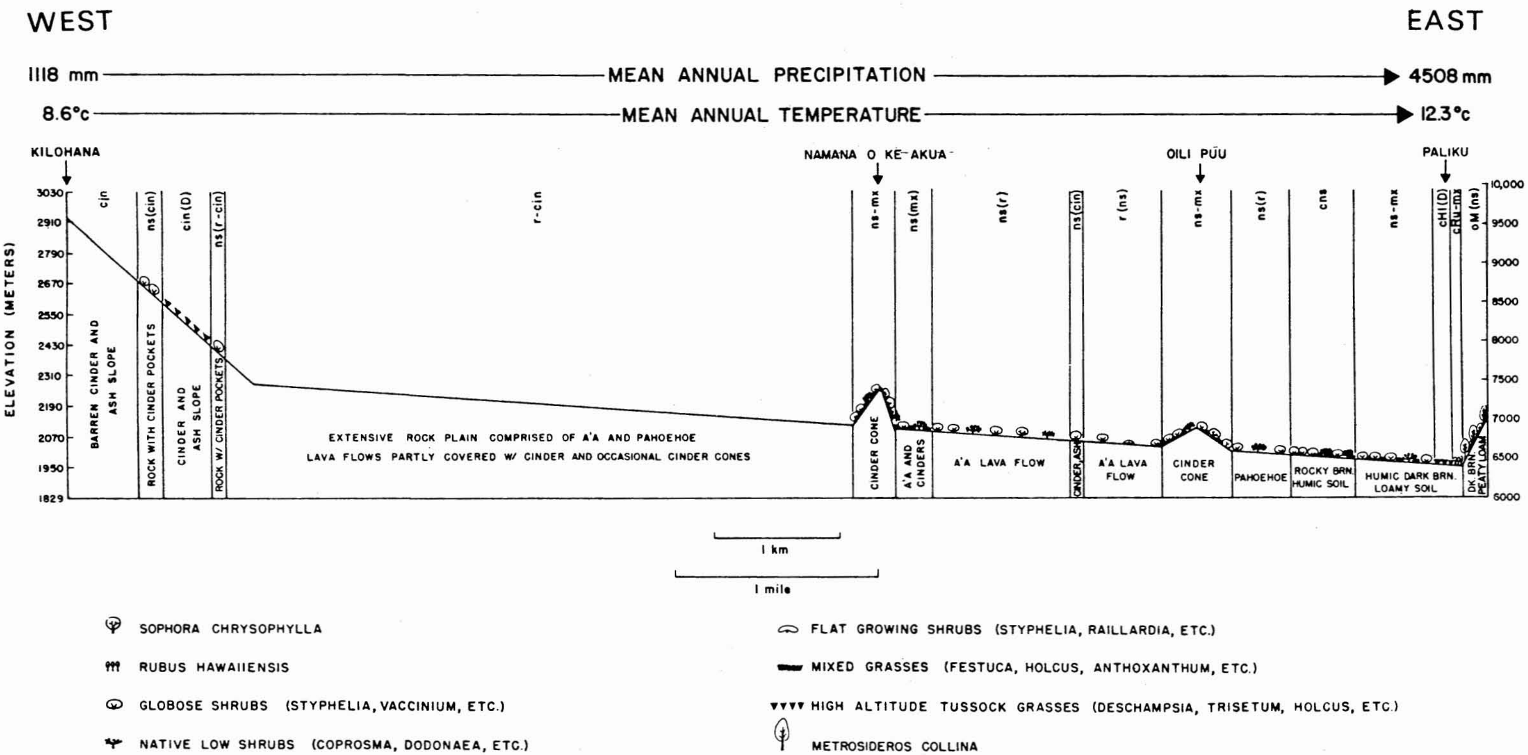


FIGURE 7. Topographic vegetation profile 2.

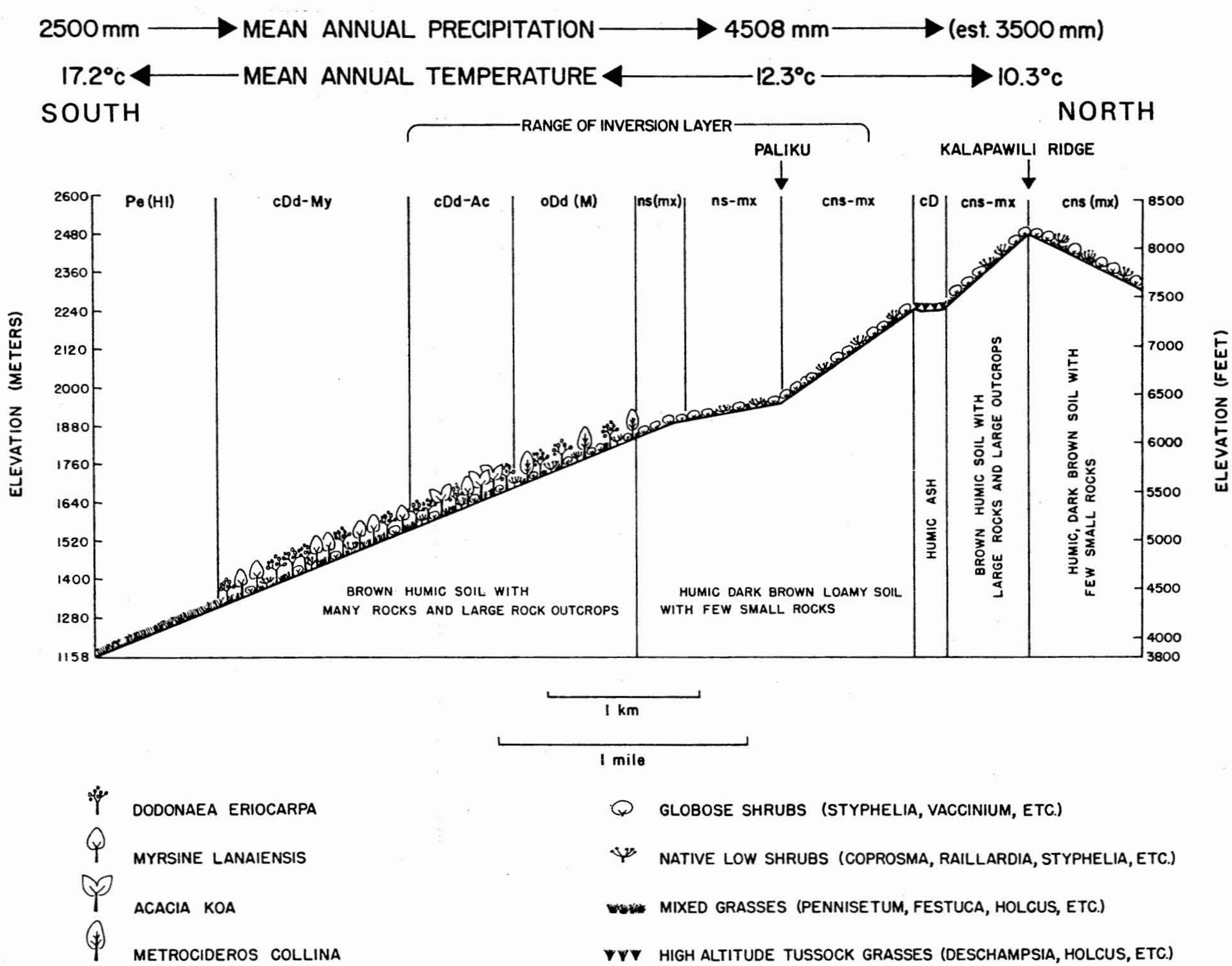


FIGURE 8. Topographic vegetation profile 3.

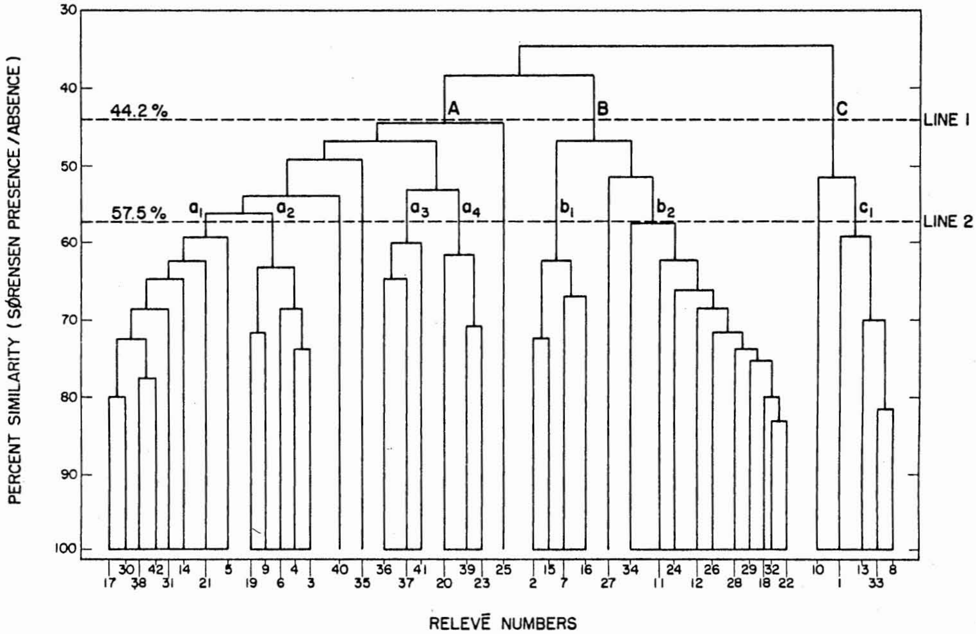


FIGURE 9. Dendrograph from Sørensen's presence/absence indices of similarity for relevé data.

on the island of Hawaii (Mueller-Dombois 1967).

In profile 2 (Figure 7) an increase in mean annual temperature is associated with the decrease in elevation, and an increase in mean annual precipitation is associated with the west-to-east orientation. The increase in rainfall is related to greater exposure to the effects of the predominant northeast trade winds. These factors result in a gradual increase in cover and stature of the vegetation from low-growing, very sparse vegetation (high-altitude desert), through several variations of scrub communities, to a rain forest, which is of low stature.

In profile 3 (Figure 8) a decrease in mean annual temperature is associated with the increase in elevation, and an increase in mean annual precipitation resulting from greater exposure to the effects of the northeast trade winds is associated with the south-to-north orientation. The lower end of the profile also extends below the inversion layer, which occurs between 1700 and 2300 m (5000–7000 ft) elevation (Blumenstock and Price 1967). This factor complex is associated with the occurrence of several forest communities between 1292 and 1890 m (4240–6200 ft), which are unique to this section of the study area.

These profiles also show the relation between substrate and community type. Matching correlations include open tussock grasslands on cinder and ash slopes, scrub communities with little or no grass matrix on rocky substrates, scrub communities with grass matrix on moderately rocky cinder and ash derived soils, and closed cover grasslands on deep, fine textured cinder and ash derived soils that occur on almost level ground. These correlations, of course, do not explain all causative relations since soil and vegetation each influence the composition of the other and both are under the influence of the climate.

FLORISTIC COMMUNITY ANALYSES

Dendrograph Analysis

Figure 9 is the final dendrograph produced based on Sørensen's presence/absence method of calculation (Mueller-Dombois and Bridges 1975). Two cutoff lines were used for the objective identification of dendrograph clusters. Because the purpose of this analysis was to identify ecologically meaningful clusters, the first line (line 1 in Figure 9) was drawn such that no relevés were left unclustered. This condition was fulfilled at a within-group similarity of 44.2 percent and it identifies three major clusters (A, B, and C). Line 2 in Figure 9 was drawn at a level that isolates seven more narrowly defined clusters with a minimum of single clusters. The seven clusters (a_1, a_2, a_3, a_4, b_1, b_2, and c_1) were isolated at a within-group similarity of 57.5 percent, which left five relevés unclustered (40, 35, 27, 25, and 10), or only 12 percent of the total number of relevés.

The three lower similarity clusters (A, B, and C in Figure 9) divide the vegetation into structural categories. Cluster A groups scrub and forest relevés, cluster B groups grassland relevés, and cluster C groups high-altitude desert relevés. The seven higher similarity clusters subdivide the lower similarity clusters into finer vegetation types. The five relevés not included in the higher similarity clusters were left as single clusters since they are unique in the study area in some way. Four subclusters and three unclustered relevés resulted from subdividing the broad woody vegetation group of cluster A. Cluster a_1 (relevés 17, 21, 30, 38, 5, 14, 42, and 31) represents native scrub communities characterized by *Styphelia* and *Vaccinium*; cluster a_2 (relevés 3, 6, 9, 19, and 4) represents scrub communities characterized by *Sophora* and *Coprosma*; cluster a_3 (relevés 36, 37, and 41) represents forest and scrub communities with *Dodonaea* phanerophytes in the tallest vegetation layer; and cluster a_4 (relevés 20, 23, and 39) represents native scrub communities with sparse (less than 30 percent) cover on rocky substrates. Relevé 35 is an open, *Acacia koa* forest community with many exotic species in the herbaceous layer that are not found elsewhere in the study area. Relevé 25 is an open, low-stature, *Metrosideros* forest community. It is included in the woody community type in the low-similarity clusters because the understory is dominated by shrub species. Relevé 40 is a scrub community dominated by *Styphelia* (cluster a_1), but it is located at a relatively low elevation and contains several species in the herbaceous layer that are unique within the study area.

The grassland communities (cluster B) were subdivided into two subclusters (which seem to be based on the presence or absence of *Holcus lanatus*) and one unclustered relevé. Cluster b_1 combines grassland relevés (2, 7, 15, and 16) in which *Holcus* is absent. Cluster b_2 combines grassland relevés (11, 12, 18, 22, 24, 28, 29, 32, and 34) in which *Holcus* is present. Relevé 27 is an open, low-stature, *Metrosideros* forest community. It was included in the grassland communities in the low-similarity clusters because its understory included two grass species of wide distribution within the study area, *Holcus lanatus* and *Deschampsia australis*.

Cluster c_1 (relevés 13, 8, 33, and 1) combines all but one of the high altitude desert relevés in cluster C. Relevé 10 is a high-altitude desert community that contains only three species with less than 1 percent total cover, and therefore this relevé is not qualitatively similar enough to be included in the high-similarity cluster (cluster c_1).

These results are summarized in Figure 10, in which the clusters and unclustered relevés were extracted to clarify the discussed vegetation type relationships. Cluster designations appear on the left side of the figure and relevé numbers along the top.

Synthesis Table Analysis

The Ceska and Roemer (1971) program produced five synthesis tables corresponding to the five combinations of criteria utilized. Of these, the 66/33 option (Mueller-Dombois and Bridges 1975) appeared to give the best representation of the data since it produced the smallest number of relevés that did not contain a species group; thus it had the greatest number of relevés with some basis to group them into vegetation types. This option resulted in eight species groups. The order of the relevés in the table was manually rearranged to show more clearly the distribution of these species groups.

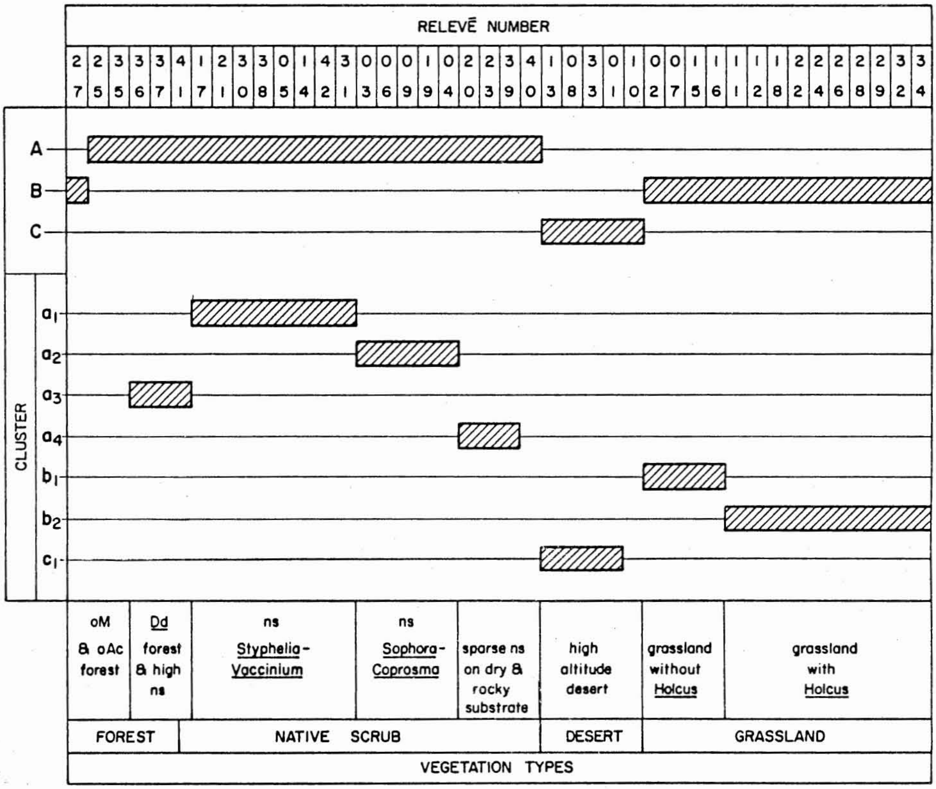


FIGURE 10. Summary chart of dendrograph clusters (Fig. 9) from Sørensen's presence/absence indices of similarity of relevé data.

A summary chart (Figure 11) was constructed from the data in the final synthesis table following a format developed by Mueller-Dombois and Bridges (1975) to further clarify the information displayed in the synthesis table. The species group numbers from the synthesis table are listed on the left side of the chart in the same sequence as in the synthesis table. For drawing boundary lines Mueller-Dombois and Bridges suggested the criterion of having at least two group limits to indicate a boundary. However, in the present study the analysis resulted in much overlapping of group limits. Therefore, boundary lines were often drawn at the limits of one group using the knowledge of the vegetation gained while working in the field. A ninth species group, discussed below, was added; this group is composed of three nearly ubiquitous herbaceous species, *Hypochoeris radicata*, *Deschampsia australis*, and *Holcus lanatus*.

Nine vegetation types were identified and have been indicated in Figure 11. The first forest type is an open *Acacia koa* forest that is unique in the study area. It is the only vegetation type composed of a single sample plot, relevé 35. The presence of species group 5 associates this type with the *Dodonaea* forest, but the koa forest lacks species group 6 and contains a number of ungrouped species that are found nowhere else in the study area. The next type is defined by species group 1 (*Fragaria chiloensis*, *Vaccinium berberifolium*, *Dryopteris paleacea*, *Metrosideros collina*, *Vaccinium calycinum*, *Uncinia uncinata*, and *Rubus hawaiiensis*) and includes relevés 25 and 27. These two sites are not identical, however, as indicated by the occurrence of species group 2 (*Lysimachia* sp. and *Myrsine lanaiensis*) in

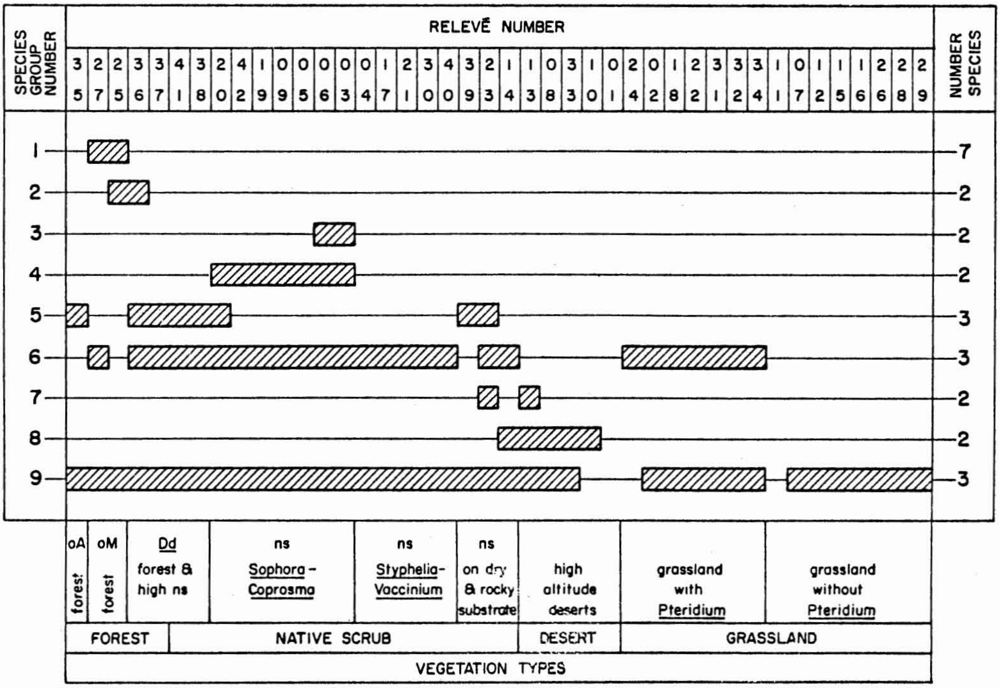


FIGURE 11. Summary chart of data from final synthesis table using 66/33 option for relevé data.

relevé 25 and a number of species unique to each site listed among the ungrouped species. The third type is composed of forest and native scrub sites containing *Dodonaea* phanerophytes in the tallest vegetation layer. This type is described by relevés 36, 37, 38, and 41, and is defined by the common occurrence of species group 6 (*Pteridium aquilinum*, *Styphelia tameiameiae*, and *Rumex acetosella*) and species group 5 (*Eupatorium adenophorum*, *Dodonaea eriocarpa*, and *Osteomeles anthyllidifolia*).

The first native scrub community type can be termed a *Sophora-Coprosma* association according to the composition of definitive species group 4 (*Coprosma montana* and *Sophora chrysophylla*) and the discussion of the association concept in Mueller-Dombois and Ellenberg (1974). This community type includes relevés 20, 42, 19, 9, 5, 6, and 3. Relevés 6 and 3 comprise a variation of this type as indicated by the presence of species group 3 which includes only two species, *Geranium cuneatum* and *Anthoxanthum odoratum*. The fifth community type identified can be termed a *Styphelia-Vaccinium* association since *Styphelia tameiameiae* is the only shrub species in species group 6, the only group present, and *Vaccinium reticulatum*, an ungrouped species, occurs in four of the five relevés included in this type. These five relevés are 4, 17, 21, 30, and 40.

The next community type is composed of three relevés (39, 23, and 14) that contain elements of several species groups from both the native scrub community types and the high-altitude desert community type. These open to sparse-cover, native scrub communities occur on rocky substrates. They may be considered transitional between the native scrub and desert community types. Next to be identified is the high-altitude desert community type, composed of relevés 13, 8, 10, 33, and 1, whose dominant surface feature is rock substrate, cinder substrate, or both. This type is defined by species group 8 which contains

TABLE 4

COMPARISON OF RELEVÉ GROUPING OF THE TWO PHYTOSOCIOLOGICAL ANALYSES OF RELEVÉ DATA*

GROUP	RELEVÉS: SYNTHESIS TABLE	RELEVÉS: DENDROGRAPH
Acacia forest	35	25, 27, 35
Metrosideros forest	25, 27	
Dodonaea forest and native scrub	36, 37, 41, 38	36, 37, 41
Styphelia-Vaccinium association	17, 21, 30, 4, 40	17, 21, 30, 5, 14, 31, 38, 42
Sophora-Coprosma association	3, 6, 9, 19, 5, 20, 42	3, 6, 9, 19, 4
Native scrub on dry and rocky substrates	23, 39, 14	23, 39, 20, 40
Grassland without *Holcus*		2, 7, 15, 16
Grassland with *Holcus*		11, 12, 18, 22, 24, 26, 28, 29, 32, 34
Grassland without *Pteridium*	2, 18, 22, 24, 31, 32, 34	
Grassland with *Pteridium*	7, 11, 12, 15, 16, 26, 28, 29	

*Core group relevés that occur in the same group by both analyses are underlined.

two species adapted to these extreme conditions, *Tetramolopium humile* and *Asplenium trichomanes*.

The next community type is grassland, distinguished by the presence of species group 6. The type is distinguished by the bracken fern, *Pteridium aquilinum*, since *Styphelia* is only sparsely represented in these seven grassland relevés (2, 18, 22, 24, 31, 32, and 34). The last community type is grasslands, distinguished by the absence of species group 6 and therefore *Pteridium*, and the presence of species group 9 composed of three nearly ubiquitous herbaceous species, *Hypochoeris radicata*, *Holcus lanatus*, and *Deschampsia australis*. Relevés 7, 11, 12, 15, 16, 26, 28, and 29 describe this community type.

Comparison of the Phytosociological Analyses

Both the synthesis table and the dendrograph analysis produced similar vegetation types (Table 4). Relevés that are in the same community type by both analyses can be thought of as a core group of sample plots that best illustrate the community type. Such core groups include relevés 17, 21, and 30 for the *Styphelia-Vaccinium* association, and relevés 3, 6, 9, and 19 for the *Sophora-Corposma* association. These core groups are underlined in Table 4. However, some variation exists in the relevés contained in corresponding vegetation community types depending on the analysis technique. These relevés can be interpreted as intermediate or transitional between the two community types in which a given relevé occurs. For example, relevé 38 occurs in the *Dodonaea* forest and native scrub community type by the synthesis table analysis that used associated species groups, but it occurs in the *Styphelia-Vaccinium* association by the dendrograph analysis that uses the total qualitative similarity of the relevés. Therefore, relevé 38 can be interpreted as intermediate between these two community types. This is presumably related to an intermediate position on one or more environmental gradients between the core group relevés of the two types. Similar observations imply that relevés 4, 5, and 42 are intermediate between the *Styphelia-Vaccinium* association and the sparse, native scrub type on dry, rocky substrates. The relevés that make up the high-altitude desert type are identical for both analyses, as are the relevés that make up the open *Metrosideros* and *Acacia* types. However, the latter two community types are lumped together in the dendrograph analysis.

Grassland communities were divided into two community types by both analyses, but the basis for the division was not the same in both cases. The synthesis table analysis using associated species groups separated grasslands containing species group 6 from those without that group. In those relevés this implies the presence or absence of *Pteridium aquilinum*, since *Styphelia tameiameiae*, a shrub species, is rare or absent in these grassland relevés. This is presumably related to some complex of environmental variables, since no single variable can be correlated with the distribution of these community types from the data collected in this study. The dendrograph analysis, using total qualitative similarity, separated two groups that seem to be based on the presence or absence of *Holcus lanatus*, since the species list of every relevé in cluster b_2 contains that species whereas it is absent from the species list of all the relevés in cluster b_1. This separation seems to be associated with a moisture gradient since all the relevés without *Holcus* are dry sites while all the relevés with *Holcus* are mesic or wet sites; that is, *Holcus* seems not to be adapted to growing in a dry situation.

Because each analysis used a different basis for separation of the community types within the structurally defined grassland type, no intermediate relevés could be identified for grasslands. However, relevé 31 seems to be intermediate between a grassland community type and a scrub community type. The synthesis table analysis groups this relevé with grasslands, while the dendrograph analysis groups it with scrub communities. Therefore, this relevé can be interpreted as a very open scrub community with a grass matrix, or as a grassland community with scattered shrubs, as indicated on the map.

These ten groupings distribute the mapped vegetation units into floristically distinguished community types within basic structural community types. Within the forest community type, subdivisions dominated by *Acacia koa*, *Metrosideros collina*, and *Dodonaea eriocarpa* were distinguished. Ten of the eleven mapped vegetation units classified as forest fit within these subdivisions (Table 2).

Within the scrub community type there occurred four subdivisions. These were scrub areas dominated by *Dodonaea eriocarpa*, a *Styphelia-Vaccinium* association, a *Sophora-Coprosma* association, and scrub areas with open to sparse cover of mixed floristic composition on dry and rocky substrates. Nineteen mapped vegetation units were of the scrub community type (Table 2), of which only two could not be distributed to one of these floristic subdivisions. These were the closed *Eupatorium adenophorum* scrub with mixed grasses and the closed *Rubus hawaiiensis* scrub with mixed grasses. These were of rather limited distribution (Table 3) and were not sampled, therefore they were not included in the phytosociological analyses.

The grassland community type was subdivided into four floristic community types. The synthesis table seemed to subdivide grasslands on the basis of the presence or absence of *Holcus lanatus*. The dendrograph analysis seemed to subdivide grasslands on the basis of the presence or absence of *Pteridium aquilinum*. Included in the structurally defined grassland type were 14 mapped vegetation units.

The high-altitude desert community type was not subdivided by these analyses. All five relevés that sampled this community type were grouped together by both analyses. Nine mapped vegetation units were included in this type (Table 2).

These analyses show that the Crater District of Haleakala National Park contains mappable vegetation units that can be grouped into floristic subdivisions of several of the community types characteristic of tropical alpine and subalpine ecosystems. These are ericaceous scrub, tussock grassland, and high-altitude desert. Only arborescent and rosette life forms do not occur as mappable vegetation units as they do in other tropical, high mountain areas. However, a woolly candle type species (Whiteaker 1978), the silversword (*Argyroxiphium sandwicense*), does occur in the study area, but its distribution is limited to colonies in cinder cone areas and to an enclosure on the outside slope that is protected and maintained by the park (Kobayashi 1973). Early accounts, however, describe this species as being common throughout the crater as well as on the outside slope (Ruhle 1959, Larson 1969). Subsequently, the silversword has had its distribution in the area restricted because of vandalism by humans and grazing by feral goats (Ruhle 1959, Larson 1969, Kobayashi 1973). At one time, then, *Argyroxiphium* may have been a significant component of mappable vegetation units within the Crater District of Haleakala National Park. Thus, the hypothesis proposed for this study is at least partially supported by the results, with a good probability that the undisturbed vegetation contained all four of the characteristic community types.

SUMMARY AND CONCLUSIONS

The major focus of this study was the production of a vegetation map of the Crater District of Haleakala National Park at a scale of 1 : 24,000 that can be used as an overlay of the USGS 1 : 24,000 topographic quadrangle maps. Fifty-three structural-floristic communities were mapped and grouped into four structural vegetation types. These were forest, scrub, grassland, and high-altitude desert communities. Areas were calculated for each community using an electronic planimeter. The total area mapped was 7544.8 hectares (18,643 acres).

Topographic vegetation profiles were constructed that show changes in vegetation types in relation to climatic gradients. Matching correlations were observed between substrates and community types.

Phytosociological analysis of relevé data by the dendrograph technique and the synthesis table technique resulted in an ecologically meaningful grouping of the sample stands. The analyses resulted in similar groupings, but detailed comparison of the results revealed interesting minor variations. Relevés that were left ungrouped were interpreted as ecologically unique within the sampling area.

The 10 groupings from the phytosociological analyses distribute the mapped vegetation units into floristically distinguished community types within basic structural community types. Ten of 11 mapped vegetation units classified as forest fit into three floristically distinguished forest community types. Four floristic community types contained 17 of 19 mapped vegetation units classified as scrub communities. Fourteen mapped vegetation units classified as grasslands were distributed into two of four floristic community types depending on the analysis technique. The high-altitude desert community type was not subdivided floristically by either analysis and included nine mapped vegetation units.

It was concluded that the Crater District of Haleakala National Park contains mappable units that can be grouped into floristic subdivisions of three of the four community types characteristic of tropical alpine and subalpine ecosystems: ericaceous scrub, tussock grassland, and high-altitude desert. Arborescent and rosette life forms do not occur as mappable vegetation units as they do in other tropical, high mountain areas. However, an endemic woolly candle type species, *Argyroxiphium sandwicense*, has had its distribution restricted because of vandalism and grazing. At one time this species may have been a significant component of mappable vegetation units within the study area. Thus, the hypothesis proposed for this study is at least partially supported by the results, with a good probability that the undisturbed vegetation contained all four of the characteristic community types.

LITERATURE CITED

BERGER, A. J., J. BEARDSLEY, R. BURKHART, P. HIGASHINO, W. J. HOE, C. W. SMITH, and H. E. SMITH. 1976. Haleakala National Park resources basic inventory 1975 narrative report. Cooperative National Park Resources Studies Unit Hawaii, Techn. Rept. No. 9. University of Hawaii, Honolulu.

BLUMENSTOCK, D. I., and S. PRICE. 1967. Climates of the states: Hawaii. U.S. Department of Commerce, Environmental Science Services Administration, Washington, D.C.

CARLQUIST, S. 1970. Hawaii, a natural history. Natural History Press, New York. 463 pp.

CARR, G. D. 1978. Chromosome numbers of Hawaiian flowering plants and the significance of cytology in selected taxa. Amer. J. Bot. 65(2): 236–242.

CESKA, A., and H. ROEMER. 1971. A computer program for identifying species-relevé groups in vegetation studies. Vegetatio 23: 255–277.

CLINE, M. G., ed. 1955. Soil survey of the territory of Hawaii, islands of Hawaii, Kauai, Lanai, Maui, Molokai, and Oahu. U.S. Department of Agriculture Soil Conservation Service in cooperation with the Hawaii Agricultural Experiment Farm. Soil Survey Ser. 1939, No. 25.

FOREHAND, S. 1970. The phytosociology of an alpine tussock grassland on East Maui, Hawaii. M.A. thesis, California State College, Los Angeles.

KOBAYASHI, H. 1973. Ecology of the silversword, *Argyroxiphium sandwicense* D.C. (composite) Haleakala Crater, Hawaii. Ph.D. dissertation, University of Hawaii, Honolulu.

LARSON, J. W. 1969. Haleakala National Park natural resources plan. U.S. Dept. of the Interior, National Park Service, Washington, D.C.

MACDONALD, G. A., and A. T. ABBOTT. 1970. Volcanoes in the sea; the geology of Hawaii. University of Hawaii Press, Honolulu. 441 pp.

MCCAMMON, R. B., and G. WENNIGER. 1970. The dendrograph. State Geological Survey, University of Kansas, Computer Contribution No. 48, pp. 1–17.

MUELLER-DOMBOIS, D. 1967. Ecological relations in the alpine and subalpine vegetation on Mauna Loa, Hawaii. J. Indian Bot. Soc. 46(4): 403–411.

MUELLER-DOMBOIS, D., and K. W. BRIDGES. 1975. Integrated island ecosystem ecology in Hawaii. Spatial distribution of island biota, introduction. P. 2, chap. 6 of proposed synthesis volume for US/IBP series. US/IBP Island Ecosystems IRP Techn. Rept. No. 66.

MUELLER-DOMBOIS, D., and H. ELLENBERG. 1974. Aims and methods of vegetation ecology. John Wiley, New York. 547 pp.

MUELLER-DOMBOIS, D., and F. R. FOSBERG. 1974. Vegetation map of Hawaii Volcanoes National Park. Cooperative National Park Resources Studies Unit Hawaii, Techn. Rept. No. 4. University of Hawaii, Honolulu.

RUHLE, G. 1959. A guide to the crater area of Haleakala National Park. Hawaii Natural History Assn., Hawaii National Park, Hawaii.

STEMMERMANN, L., C. W. SMITH, and W. J. HOE. 1979. Haleakala National Park Crater District resources basic inventory 1976–1977 narrative report. Cooperative National Park Resources Studies Unit Hawaii, Techn. Rept. No. 24. University of Hawaii, Honolulu.

U.S. SOIL CONSERVATION SERVICE. 1972. Soil survey of the islands of Kauai, Oahu, Maui, Molokai, and Lanai, State of Hawaii. U.S. Dept. of Argiculture Soil Conservation Service in cooperation with Univ. of Hawaii Agricultural Experiment Station.

VOGL, R. J. 1971. General ecology of the northeast outer slopes of Haleakala Crater, East Maui, Hawaii. Contributions from the Nature Conservancy No. 6. Arlington, Virginia.

WHITEAKER, L. D. 1978. Haleakala—a tropical alpine and subalpine area. Newsl. Haw. Bot. Soc. 17(3/5): 36–53.

———. 1980. The vegetation and environment in the Crater District of Haleakala National Park. Cooperative National Park Resources Studies Unit Hawaii, Techn. Rept. No. 35. University of Hawaii, Honolulu.

YOCUM, C. F. 1967. Ecology of feral goats in Haleakala National Park, Maui, Hawaii. Amer. Midland Naturalist 77(2): 418–451.